



Criticality benchmark of the Molten Salt Reactor Experiment

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Molten Salt Reactor Workshop 2017 | Key Technology and Safety Issues for MSRs

October 3, 2017



A peer-reviewed reactor physics benchmark for molten salt technologies is under development

- DOE NE awarded an NEUP to UC Berkeley, in collaboration with ORNL and the Grenoble Institute of Technology (France), to create an MSRE benchmark (October 2016)
- The target is to create a benchmark for the International Reactor Physics Benchmark Experiment Evaluation Project (IRPhEP) handbook
 - peer-reviewed set of reactor physics-related integral data
 - used by reactor designers to validate analytical tools for advanced reactors
 - used by safety analysts to establish the safety basis for operation of advanced reactors





The benchmark is based on a series of start-up zero-power experiments (June 1965)

- An initial criticality experiment measured the minimum amount of ²³⁵U needed to reach criticality
- Measurements of the differential worth of one control rod as a function of position with stationary and circulating salt
- Measurements of the integral worth of various control rod configurations
- Criticality configurations obtained changing ²³⁵U concentration and control rod positions;
- Measurements with stationary and circulating salt conditions
- Measurement of the whole core isothermal temperature reactivity coefficient
- Measurement of the pressure reactivity coefficient



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Creating a benchmark consists of two main tasks

- Create benchmark specifications
 - Retrieve data and related uncertainty
 - Make assumptions as needed
- Test the benchmark
 - Create and run one or more computational models
 - Assess uncertainties

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Fuel geometry





ARRANGEMENT



Top components







Fig. 5.13. Control Rod Poison Element.









Core model



Horizontal cross section of the MSRE model



Dowel section of graphite lattice



FIG. 5.6. TYPICAL GRAPHITE STRINGER ARRANGEMENT



Horizontal cross section of the dowel section of the graphite lattice



Taper region



Horizontal cross section of the taper region

Control rods and sample baskets

Horizontal cross section of the control rods and sample baskets

Sample baskets

Overall model

ELEVATION

The benchmark model was tested on the first MSRE criticality experiment

- Fuel salt composition $65\text{LiF}-29.2\text{BeF}_2-5\text{ZrF}_4-0.8\text{UF}_4$ (99.99% for ⁷Li enrichment).
- Fuel salt density 145.3 ± 1.0 lb/ft³ (2.3275 ± 0.0160 g/cm³)
- Mass fraction of 235 U in the salt is 1.408 ± 0.007 wt%
- Core temperature 1,181°F (638°C)
- One rod was inserted at 46.6 in. position, other two rods at their upper limits

Case	k _{eff}	100(C-E)/E
Benchmark	1.0	-
Calculated (SERPENT2, ENDF/B-VII.1 cross sections)	1.01276 ± 0.000098	1.276

Graphite density is the major source of uncertainties on $k_{\rm eff}$

Item	Nominal and bounding values	Δ k × 10 ⁻⁵	
Graphite density	(1.87±0.02) g/cm ³	349	
Fuel salt density	(2.3275±0.0160) g/cm ³	83	
²³⁵ U mass fraction in the salt	(1.408±0.007) wt%	61	
INOR-8 density	(8.7745±0.0200) g/cm ³	9	
Graphite core height	(166.446±1) cm	19	
Graphite core radius	(70.168±0.2) cm	13	
Fuel channel width	(1.016±0.127) cm	100	
Fuel channel length	(3.048±0.127) cm	42	
⁶ Li enrichment	(0.01± 0.001) at. %	174	
Boron concentration in graphite	(0.00008±0.00008) wt. %	18	
Outlet pipe height	39.687 cm (1σ = 4 cm)	31	
Distributor thickness	0.819 cm (1σ = 0.08 cm)	29	
Sample basket shell dimension	remove one INOR-8 plate	16	
INOR-8 composition	0.06% (C mass fraction), 0.08%	10	
Total (root mean square)		422	

The largest sensitivity coefficients for k_{eff} from cross section data uncertainties are for C and $^{235}\mathrm{U}$

Nuclide	Total	Elastic scattering	Disappearance	Fission
Li-6	-0.0286	0.0000	-0.0286	-
Li-7	0.0040	0.0165	-0.0139	-
Be-9	0.0251	0.0283	-0.0033	-
Zr-90	0.0014	0.0018	-0.0006	-
Zr-91	-0.0060	0.0005	-0.0066	-
Zr-92	-0.0007	0.0008	-0.0016	-
Zr-94	-0.0002	0.0001	-0.0005	-
Zr-96	-0.0006	0.0002	-0.0008	-
F-19	0.0749	0.0705	-0.0105	-
C-nat	0.5212	0.3970	-0.018	-
B-10	-0.0064	0.0000	-0.0064	-
U-235	0.2386	0.0003	-0.1386	0.3768
U-238	-0.0857	0.0056	-0.0921	0.0006

Conclusions

- A set of benchmarks based on the MSRE is under development
- The evaluations will include multiple benchmarks following the zero-power experiments campaign of June 1965
- A draft benchmark of the first criticality obtained varying ²³⁵U concentration with steady salt is under review for inclusion in the Reactor Physics Benchmark Experiment Evaluation Project (IRPhEP) Handbook
- If you are interested in the draft benchmark email us: maxfratoni@berkeley.edu

Acknowledgements

Evaluators

External reviewer

Dan Shen UC Berkeley

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ORNL

Jeff Powers ORNL

Adrien Bidaud Grenoble Institute of Technology, France

Luka Snoj Jozef Stefan Institute, Slovenia

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